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Gas boosted solar water heaters: Queensland case studies of installation practices in new homes

Wendy Miller[1]
[1]Senior Research Fellow, Built Environment and Engineering
Queensland University of Technology
GPO Box 2434 Brisbane Australia
W2.miller@qut.edu.au

Professor Laurie Buys[2]
School of Design, Queensland University of Technology
GPO Box 2434 Brisbane, Australia
l.buys@qut.edu.au

ABSTRACT

Because of the greenhouse gas emissions implications of the market dominating electric hot water systems, governments in Australia have implemented policies and programs to encourage the uptake of solar water heaters (SWHs) in the residential market as part of climate change adaptation and mitigation strategies. The cost-benefit analysis that usually accompanies all government policy and program design could be simplistically reduced to the ratio of expected greenhouse gas reductions of SWH to the cost of a SWH. The national Register of Solar Water Heaters specifies how many renewable energy certificates (RECs) are allocated to complying SWHs according to their expected performance, and hence greenhouse gas reductions, in different climates. Neither REC allocations nor rebates are tied to actual performance of systems.

This paper examines the performance of instantaneous gas-boosted solar water heaters installed in new residences in a housing estate in south-east Queensland in the period 2007 – 2010. The evidence indicates systemic failures in installation practices, resulting in zero solar performance or dramatic underperformance (estimated average 43% solar contribution). The paper will detail the faults identified, and how these faults were eventually diagnosed and corrected. The impacts of these system failures on end-use consumers are discussed before concluding with a brief overview of areas where further research is required in order to more fully understand whole of supply chain implications.

Keywords – installation practices, gas boosting, RECs, solar water heaters, market diffusion, climate change policy

INTRODUCTION

Solar water heating (SWH) technologies contribute significantly to water heating markets in many countries (e.g. Austria, Israel, Turkey, China) and to a smaller extent in many other countries (about 7% in Australia). As in other countries (Wallace and Wang 2006), initial Australian government support programs for this technology focused on quality control (e.g. development of Australian Standards; establishment of testing and certification processes), cost reduction and industry development. Because the greenhouse gas emissions from the Australian market-dominating electric resistive water heaters are much higher than for alternative water heating technologies (refer to Figure 1), governments in Australia have implemented policies and programs to encourage the uptake of SWHs in the residential market as part of climate change adaptation and mitigation strategies. Current government initiatives incorporating SWHs include Australia's expanded Renewable Energy Target Scheme (August 2009); national and state based rebates; and the National Strategy for Energy Efficiency (Senior Officials Group on Energy Efficiency 2010).

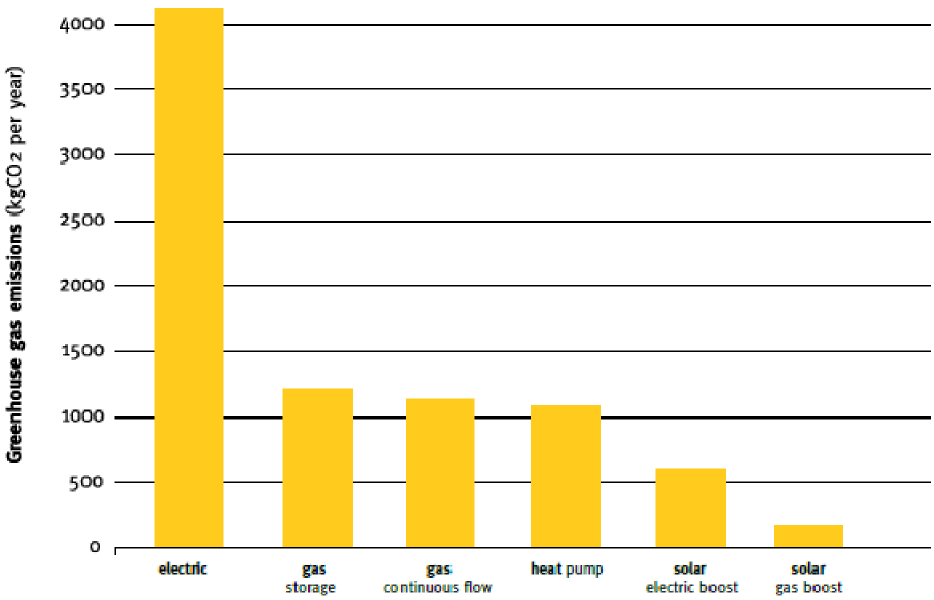

Fig. 1: Hot water systems and emissions (Building Codes Queensland 2008)

The contribution of hot water to nationally averaged household energy use and greenhouse gas emissions is shown in Figure 2.

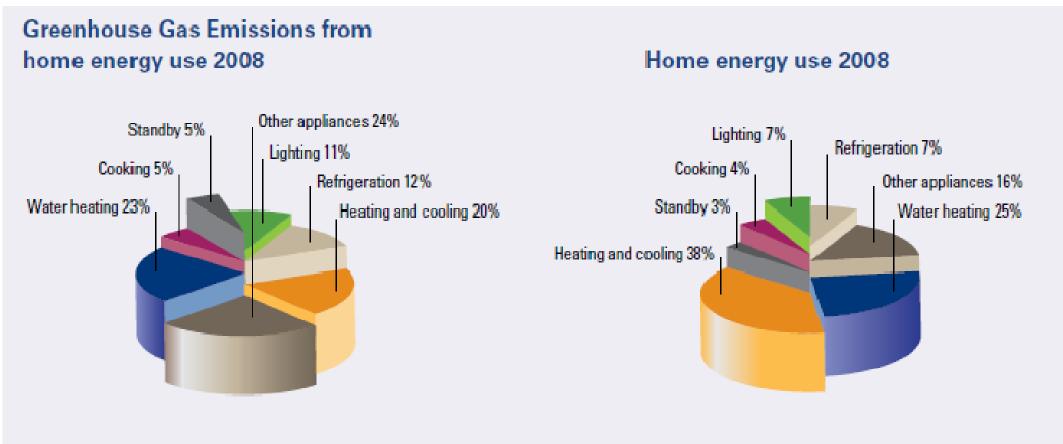

Fig. 2: Residential energy use and greenhouse gas emissions in Australia
(Senior Officials Group on Energy Efficiency 2010)

In Queensland, water heating accounts for about 27% of the electricity consumption of the average household making this single appliance one of the highest energy users and contributors to greenhouse gas emissions in the home. The Qld government, as part of its Climate Change Strategy, has taken a number of policy and regulation steps to reduce this impact, including the gradual phase out of electric resistive hot water systems in new homes from March 2006, and for replacement systems (in reticulated gas areas) from January 2010 (Department of Infrastructure and Planning 2010).

Determining Solar Water Heater Performance

How is solar water heater performance evaluated? The cost-benefit analysis that usually accompanies government policy and program design could be simplistically reduced, in this instance, to the ratio of expected greenhouse gas reductions of SWHs to the cost of a SWH. Solar water heating models are listed in the Register of Solar Water Heaters if they have received Australian and New Zealand Standard certification 2712-2002. As required by the *Renewable Energy (Electricity) Regulations 2001*, the Register of solar water heaters contains information about each SWH model for which renewable energy certificates (RECs) may be created, depending on its installation date and geographic location (and therefore solar radiation data), and therefore its expected greenhouse gas savings. To qualify for RECs, the installer of the system must be certified by an appropriate authority. Some states offer additional financial rebates and require further installation documentation such as a Certificate of Compliance or installation report (2010). For practical reasons neither REC allocations nor rebates are tied to the actual performance of installed systems.

Performance expectations and indicators

Solar water heaters are frequently promoted by both government and industry as using 'free energy from the sun', alluding to both environmental and economic benefits. The implied message, to the end user, is that these systems will maximise the solar input and minimise the need for supplementary heating, usually from fossil fuels (Caird, Roy et al. 2008). The extent to which the environmental benefits (reduced greenhouse gas emissions) and economic benefits (reduced/nil running costs) are experienced by the end user depends on a number of key variables, as shown in Table 1.

Tab. 1: Variables affecting solar water heater performance (Berrill and Blair 2007)

Geography	The climate conditions of sunshine (irradiation) The temperature of the air and of the inlet water
Manufacturers	The efficiency of the solar collector, storage tank and booster
End user	The quantity and temperature of hot water required How efficiently the system is managed by the users The annual boosting energy required and the energy source used

The installation experience and skills of tradespeople is mentioned as one of the barriers, but not a key variable (Berrill and Blair 2007).

Solar water heating in Queensland

Gas boosted solar water heaters have the greatest greenhouse gas emissions reduction potential (Figure 1), yet are not common in the Queensland market. 91% of Queensland's 135,000 solar water heaters (8% of the total market) are electrically boosted and 5% reportedly have no boosting at all (Australian Bureau of Statistics 2009). This would lead one to presume that the remaining 4% of solar water heaters utilise either wood or gas for their supplementary heating. The purpose of this research was to evaluate end-user experiences of the installation process and performance of instantaneous gas-boosted solar water heaters in south east Queensland. The aim of the research was to identify key issues experienced by the households that could lead to enhanced consumer confidence, industry credibility and government policy outcomes, in turn leading to greater market diffusion.

METHOD

This paper, utilising an extended case study, adopts a qualitative approach to identify key issues relating to the installation, operation and performance of gas-boosted solar water heaters, as experienced by end-users.

Housing context

The physical context of the case study is an Ecovillage in sub-tropical Queensland, Australia. The estate's extensive Architectural and Landscape Code encompasses the broad categories of environment protection, resource management and social cohesion. Renewable energy technologies are seen as a key means of achieving the estate's environmental and economic objectives, which also include ensuring that buildings and their users minimise energy use, particularly from fossil fuels. Both photovoltaics (minimum 1kWp) and solar water heaters are mandated. Water efficient appliances and plumbing fittings are mandated, along with rainwater tanks for all potable water supply. At the time of the study (January – June 2010) there were 50 constructed and occupied homes in the Ecovillage, just over 1/3 of planned residences. As the estate provides reticulated LPG to each lot, gas appliances are mandated for heating services such as cooking, boosting for solar water heaters, and optional space heating.

Participants

Participants for this water heating case study included eleven volunteer families (21 individuals), 22% of the completed residences in the Ecovillage at the time of the study. Each family had had a gas-boosted solar water heater installed in a new home in the period 2007 – 2010. All families live in detached off-ground dwellings (1-3 bedrooms), and household occupancy rates range from 1-3 people.

Tab. 2: Demographics of case study families

Indicator	Range / variables	Individuals / (families)
Age bracket of adults	24 – 34	1
	35 – 45	4
	45 – 60	10
	60 – 75	6
Family size	Single	(1)
	Couple with 1 child	(2)
	Couple (no children at home)	(6) working; (2) retired

Note: quotations from families are indicated by F1, F2 etc after each quotation.

Interviews

Seven of the eleven families were interviewed in their homes regarding their broad experiences of the design, construction and operation of their 'sustainable homes'. These recorded semi-structured interviews incorporated global environmental issues and personal responses to these issues, overall goals for their home, and their design and construct experiences. The recorded interviews were transcribed and coded to condense and categorise the data into key themes. Under the key theme of energy expectations and outcomes, solar water heating was identified as a significant sub-theme arising from a common major household sustainability goal of low running costs. Follow-up interviews, focusing solely on hot water issues, were conducted where necessary to clarify and explore in more depth issues raised in the initial interviews. Semi-structured interviews were then conducted with three additional families, focusing on the specific areas of initial and current solar water heating performance and fault identification/rectification processes. Two families provided additional documentation (e.g. correspondence) relating to their solar water heating systems. A number of other Ecovillage residents provided adhoc comments regarding their solar water heaters, by way of casual conversations. Their comments were used to form a general impression of the extent to which the experiences of the eleven households were reflected in the broader experience.

System Performance Data

A visual street-side inspection was used to quantify the type and number of systems in the village (see Table 3). Visual inspections of system installations were undertaken in 6 homes and photographs were taken of different types of installed systems throughout the village.

Tab. 3: census of Ecovillage solar water technologies

Size (collector and storage tank)	Flat plate, close coupled	Flat plate, pumped circulation	Evacuated tube, pumped circulation
Small (<200l, 1 panel)	3	1	
Standard (300l; 2 panel)	21	20	5 (1@500l)

All of the solar water heating systems have inline instantaneous gas boosters with electronic ignition. Such systems, theoretically, have the lowest greenhouse gas emissions as the only time fossil fuels are used for heating the water is on-demand, after taking into account the solar component. Running out of hot water is usually not an issue; the pre-eminent issue is determining how much of the hot water demand is met by the solar collectors and how much from gas. In this subtropical climate zone, the sun should be providing 86-95% of annual hot water demand (Building Codes Queensland 2008). Detailed gas consumption data for 18 months was obtained from the 11th household, through the integrated water, gas and electricity resource monitoring and control system, EcoVision. This system uses an overarching systems platform to collect and store sensor information, collate the data into predetermined criteria, and display it on an in-house touch screen display. The system's sensors and meters measure, record and display:

- General power, lighting, refrigeration, solar generation (1 pulse = 0.3125Wh)
- Potable, recycled, and hot water (1 pulse = 1 litre)
- Gas use (1 pulse = 10 litres)
- Internal temperature and humidity (5 second sampling)

The raw data from Ecovision was analysed to provide analysis of gas consumption for this family per day, month and year. Ecovision data for the remaining households was not available at the time of this study, so gas consumption figures collected by a government study of the Ecovillage were used as a default. This data represented monthly gas meter readings of 40 homes for the period April 2008 – December 2009 and made assumptions about the proportion attributable to hot water services based on comparison with data from other sources (Hood, Gardner et al. 2010).

This paper focuses on the qualitative data, i.e. the household experiences and the associated physical evidence presented through visual inspection. Full quantitative assessment of solar water heater performance will be possible once EcoVision data becomes available. This is the subject of further research for this case study.

RESULTS

Household expectations of performance

Household expectations of the performance of solar water heaters were represented by two extremes. Most families (8/11) had no previous experience with solar water heating technologies as well as no real idea of their hot water consumption levels. They could not clearly articulate what their expectations of the technology were. Any expectations were expressed in general terms relating to overall household goals of low operational costs and energy self-sufficiency as much as possible.

> *The thing is that we are not all familiar with these units and how efficient they should be. . . [we] thought that solar hot water should essentially be free. (F1)*

Three families had a high level of knowledge about the technology and/or previous experience regarding seasonal differences in hot water consumption patterns and ways to maximize technology performance to meet these needs. They had high expectations of the SWH meeting all/most of their needs. These families played an active role in the design of the hot water system, the selection of the technology and oversight of its installation. (One of these systems consisted entirely of second hand components.)

Household perceptions of performance

Household perceptions of actual solar performance (compared with expectations) could be classified into five main categories, with associated user responses.

1) No Idea – no action

Initially most families fell into this category. All families had hot water supply and assumed that most of this supply was coming from solar. They did not know how much of that supply was proportioned to solar input or to gas. They had no reference point for comparison, i.e. no previous experience with solar water heaters or gas supply for cooking and water heating. They were not particularly happy with the level of their gas bills but were not sure what that implied. They took action, eventually, as a result of the next two categories of user responses.

2) Gas bills catalyst for action

The receipt of gas bills was the catalyst for action by one family. This family had utilized bottle gas for cooking in their last residence, so had a reference point for comparison.

> *I had a sense that the [gas] bill was more than I expected, so I started asking other people what their bills were. (F1)*

These social conversations revealed that this particular family's gas consumption was 'significantly higher' than other families with conceptually similar demands. Secondly, the family was advised to keep their gas booster switched off unless required.

> *If he (neighbor) hadn't told us that we could turn the gas booster off, we would not have known that the solar was not working properly (F1)*

Subsequent interaction with the installer, and ultimately distributor, manufacturer and third party provider, lead to the causes of this system's poor performance being identified (incorrect plumbing eliminating all solar input) and successfully resolved, 2 ½ years after occupancy.

3) Incidental interaction catalyst for action

For another family, a similarly serious system fault (i.e. no solar contribution at all) was only identified per chance through one neighbor providing technical assistance with the EcoVision resource monitoring system. Once operating correctly, EcoVision showed a very high gas consumption level and a visual inspection of the hot water system at that time led to a suspicion that the system had been incorrectly plumbed two years previously. The family initiated a 'faulty performance' complaint to the installer which in turn took another 12 months to resolve, after complaints to the Building Services Authority and the Plumbing Industry Council.

4) Reasonable idea of system performance – action taken

Two families (2/11) had a reasonable idea of how their systems should be performing, because of technical expertise or previous experience with solar water heaters. This knowledge led them to believe that their systems were underperforming, and although they could not identify specific causes of the underperformance, they had sufficient confidence to take action to eventually have errors identified and rectified.

5) Good knowledge of system performance – no action required

Three families (3/11) had a very good idea of how the system was performing. For two of these families, this knowledge was due to them manually controlling the gas booster: one because of advice from a friend, the other due to previous experience with solar water heaters. The third family had not yet installed the solar booster:

> *Solar hot water is better than expected in so far as of the moment, the motivation to buy a gas booster hasn't been strong enough. (F3)*

Supply chain contact for fault identification and rectification

Once residents identified that the there was 'something wrong', various supply chain agents were contacted regarding rectification of problems: main building contractor, installer, product distributors and/or manufacturers, regulatory bodies (e.g. building certifiers and plumbing inspectors) and independent consultants. The households themselves were the key catalysts for determining who would be involved, depending on the nature of their building contract (e.g. was the building contractor responsible for the supply and install of the system), their relationship with the installing plumber (e.g. if the response time was reasonable and there were no quality issues with other plumbing tasks), and the nature of the problems (including length of time that problems had been experienced, and the number and complexity of the problems).

Their experiences with the supply chain agents varied. For some, the interactions were positive from a relationship point of view, but the technical faults still took a considerable time to identify and rectify. Other relations were very strained, resulting in households refusing to allow particular tradespeople on their properties again.

Identified system faults

The solar hot water systems of these 11 families encompassed worst case to best case performance of the technology, ranging from zero solar input (100% gas heating) to 100% solar input. Resource consumption data from Ecovillage households in the period April 2008 – November 2009 showed a higher than expected gas consumption, leading to an estimation of the average solar fraction for water heating at 43%, half of the expected performance level for this climate (Hood, Gardner et al. 2010). The householders' stories revealed a long list of faults that were eventually identified and rectified (or are still in the process of being rectified). Most faults fall into two key areas: installation errors and commissioning and certification failures (Table 4).

Tab. 4: Installation, certification and design issues limiting optimal performance

Installation related faults limiting optimal performance	
Tempering valve: setting and placement	• Tempering valves (45°C) installed prior to gas booster • Only 1 tempering valve installed (45°C) • No tempering valve installed
Plumbing of Inlet / outlet pipes for collectors and/or tanks	• Cold water inlet connected to top of collector (top manifold) on opposite side of hot water outlet • Hot outlet pipe connected to cold water inlet of collector • Collector not plumbed to tank and circulation system • Incorrect tank inlet / outlet plumbing
Circulation pump / pump controller	• No sensors installed • No solar controller installed • Excessive / poor circulation rate
Storage tanks	• Not holding heated water overnight (losing more than 5°)
Collectors on frames	• Poor securing of collectors to frames (blowing off in strong wind)
Gas booster	• Inappropriately sized gas pipes to instantaneous booster
Pipe insulation	• Not all hot water pipes insulated • Lagging melting on pipes
System commissioning / inspection / certification	
Commissioning	• No commissioning or check list completed by plumber • No testing/inspection by main contractor before payment of installation • Limited visual inspection & no performance testing by plumbing inspector or building certifier

DISCUSSION

Whilst the results are still the subject of further evaluation, initial findings raise three key issues that have implications for end-users and conceivably for supply chain agents.

1. Identifying system underperformance

The water heating industry relies on customers for fault identification:

> *A telephone call from an owner is the most common way for an installer to discover that there is a problem. (Berrill and Blair 2007)*

But without any reference point of previous experience, and no system performance monitoring mechanism, how is the owner to know there is a problem? One of the key benefits, and the key challenge, of the use of in-line gas boosters with solar collectors is that the household is unlikely to experience a loss of hot water. In this case study, householders 'tested' their assumptions of underperformance through social norming: asking neighbours how their systems were performing and comparing gas bills. Because this type of hot water system is not common in Queensland, using social norming for fault identification would have been highly improbable in any place other than an estate where such systems are mandated. Additionally, the social structure of the Ecovillage (where a high level of social interaction is designed into the layout of the residential blocks and where neighborhood sharing of knowledge, skills and resources is common place), made it socially acceptable to ask such questions. This social norming and interaction has lead to two key strategies that continue to be utilized within the village to identify water heater performance: switching off the gas booster, and looking at the total gas usage and pattern of gas usage shown on the Ecovision screen. Whilst these strategies don't reveal the exact nature of a technical problem, they do serve to alert households to the existence of a problem.

2. Main contributor to underperformance

The performance deficits identified were not related to any particular type or brand of system, or any particular installer, although there were more problems with pumped circulation systems than close-coupled systems. Plumbers were identified as the key players and installation errors could be distilled into three core issues:

- Plumbers did not understand the desired performance outcome of a solar-gas water heater i.e. maximize solar input and minimize the need for boosting.
- Plumbers did not appear to have an understanding of the 'whole system'. The specific areas that seemed least understood were pumps, pump controllers, and the connection of all parts (i.e. how water is meant to flow through the system and how each component contributes to the outcome).
- Plumbers did not use a check list or implement testing and commissioning processes to 'ensure that all component parts function normally and that the system is adjusted for optimum performance' (Berrill and Blair 2007).

Implicated in these poor installation practices are building contractors and regulatory bodies, including building certifiers, plumbing inspectors and associated authorities. Their role and responsibilities with regards to checking system operation, as part of their general construction inspection and certification processes, remains somewhat unclear and is an area of further research.

3. Effects of underperformance on end-users

The underperformance of solar-gas water heaters, in terms of customer expectations, has affected the ability of these households to meet their sustainability goals. Economically families are paying a high upfront cost for these supposedly 'elite' systems, yet have also been paying relatively high and unexpected costs for excessive gas boosting. This impacts their home mortgage costs (which pay for the initial system) and household living costs. Environmentally, the systems are not delivering the greenhouse gas savings alluded to in marketing and government publications, and installation practices have resulted in families not being able to easily control their use of the booster and hence their greenhouse gas emissions. Socially, the quality of the water service, in temperature and in seasonal availability, has been decreased.

Conversely, the social structure of the estate has enabled some level of collective problem identification.

CONCLUSION

Case studies of eleven families were utilized to explore the performance of gas boosted solar water heaters in a south-east Queensland estate. These solar-gas hot water systems are grossly under-performing. System underperformance was typically identified after lengthy time periods through resident social norming, and underperformance was attributable mainly to poor installation and lack of commissioning and inspection. The underperformance has affected the sustainability goals of the households. Early adopters of renewable energy technologies are motivated by reducing fuel consumption (Caird, Roy et al. 2008) and their experiences can inform other supply chain agents in their efforts to overcome barriers and enable the technologies to achieve their fullest potential (Faiers and Neame 2006). Poor performance impacts on the solar water heating industry through loss of product credibility and customer trust, and on governments through loss of greenhouse reduction potential. Without a coordinated whole systems approach to the diffusion of this technology into the market, everyone in the supply chain could continue to live with the illusion that the expected performance outcomes are actually being met in the market place.

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